Crystal R&D Proposal for a Forward Calorimeter at EIC

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TITLE OF PROPOSAL:

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PROPOSAL TERM (mm/yy) From 01/12 To 12/13

Abstract:

Measuring the scattered electron energy and scattering angle can determine the kinematics of DIS in an electron-ion collision. High quality crystals, such as doped PWO or BSO, are proposed to be used in a calorimeter design. A crystal calorimeter, with an energy resolution of 2-3% for 2-5 GeV electrons in a forward direction ($\eta < -2$) of the electron beam, is crucial for electron/photon identification in the EIC project. USTC has an experienced research group collaborated with SICCAS, a reliable crystal vendor, for new scintilator crystal R&D, crystal property test, etc. We proposed the crystal R&D project for a forward calorimeter including design, simulation, crystal testing, read-out electronics and prototype testing.

Very preliminary estimate of the cost:

Usage	Cost (kUSD)	
Crystal samples purchase	15	Samples for R&D and testing
R&D and testing	10	Testing system
Resist-radiation testing	10	Pre-testing, prototype beam testing
Qualified crystal purchase	45	5x5 Depends on design
PMT purchase	15	PMT read-out
APD+Electronics(preamp)	15	Read-out for prototype.
Total	110	

Proposal

1) Introduction

Studying the gluon and quark distributions in a nucleon structure and the small Bjorken-x physics is the fundamental goal of the electron-ion (ep and eA) collider (EIC). Precise measuring the scattered electron energy and scattering angle can determine the kinematics of the deep inelastic scattering (DIS), which is quantified by (x, Q^2). Figure 1 shows an example of the DIS kinematics of an e+p collision at electron and proton energies of 5 and 100 GeV, respectively. For a given scattered electron out-going angle (θ'_e) with respect to the incident electron beam, we can map the Bjorken-x coverage by measuring the scattered electron energy (E) dE/E. For very forward direction of the electron beam (η < -2), the interested scattered electron energy 2-5 GeV covers lower x region (see green curves for θ'_e = 165°). Therefore, identification of the scattered electrons and measuring the energy fraction from the incident electron beam are crucial for the EIC project.

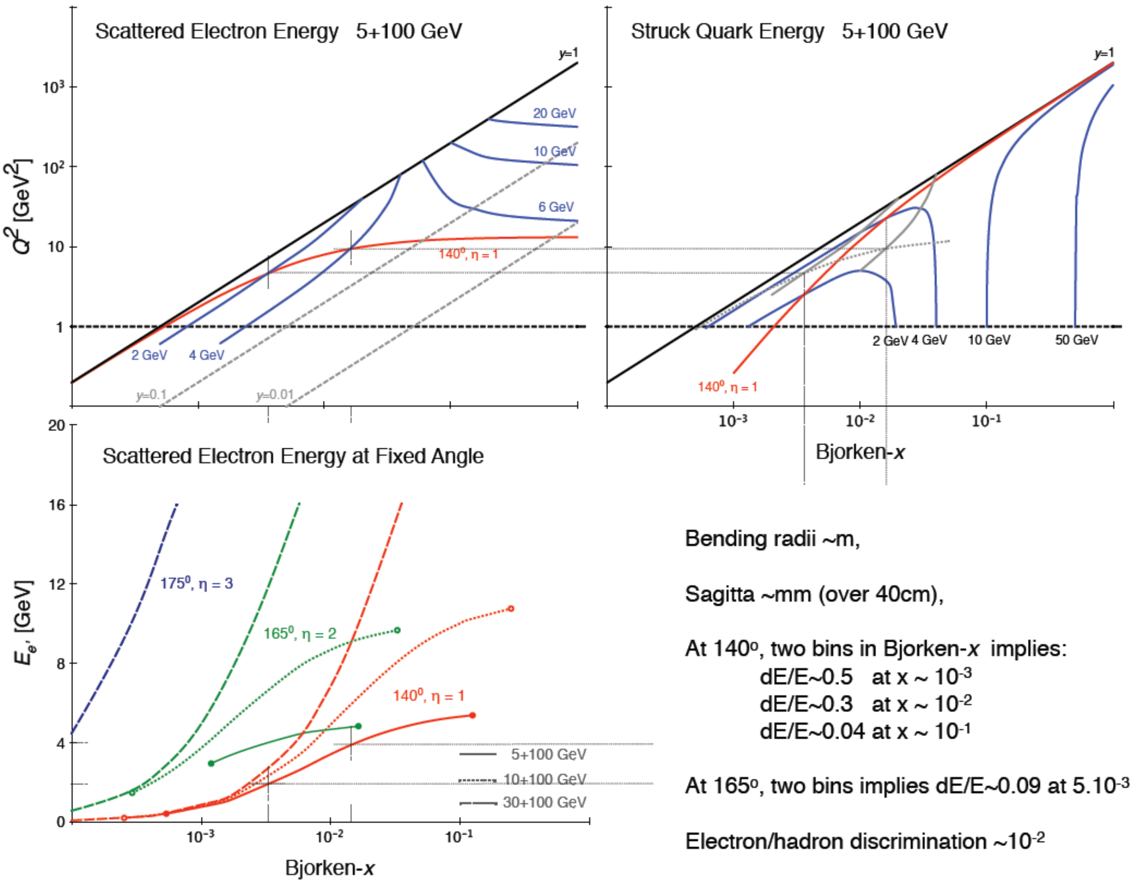

Figure 1: An example of DIS kinematics of an e+p collision.

Crystal detectors with good energy resolution have been widely used in experiments for the identification of electrons and photons. Crystal detectors can also provide trigger capability for electrons and photons. Dense crystals, such as PWO, BSO used in the detectors are required with high resistance to irradiated damage to survive in a high luminosity environment. And a high light output is also required for good energy resolution. Table I is the general properties of BSO, BGO and PWO crystals. The relative light output is normalized to that of NaI(Tl) crystal.

Crystal	Density (g cm^{-3})	Rad. length (mm)	Decay time (ns)	Peak emission (nm)	Relative light output	Price ($/cc)
BSO	6.80	11.5	~ 100	480	0.04	13-18
BGO	7.13	11.2	~ 300	480	0.10 – 0.21	> 40
PWO	8.28	8.9	~ 10-30	410 - 450	0.003	10-13

The BGO crystal has better light output, but it is expensive and is weak in resistance to irradiated damage compared with BSO and PWO crystals.

Since BSO is produced by replacing Ge in BGO with Si, the material cost for BSO is expected to be significantly reduced (about a factor of 3-4). Recently BGO price in the market keeps increasing. Another advantage for BSO is that its resistance to irradiated damage is better. Its reduction of the light output is within 10% under a <1 Gy/h dose. And its relative light output is a factor of ~10 of PWO, which is very suitable for a calorimeter requiring high energy resolution. Figure 2 shows the performance of the BSO crystal calorimeter from a 0.5-3 GeV electron beam test compared with EGS4 simulation. The energy resolution at 3 GeV is 2-3%.

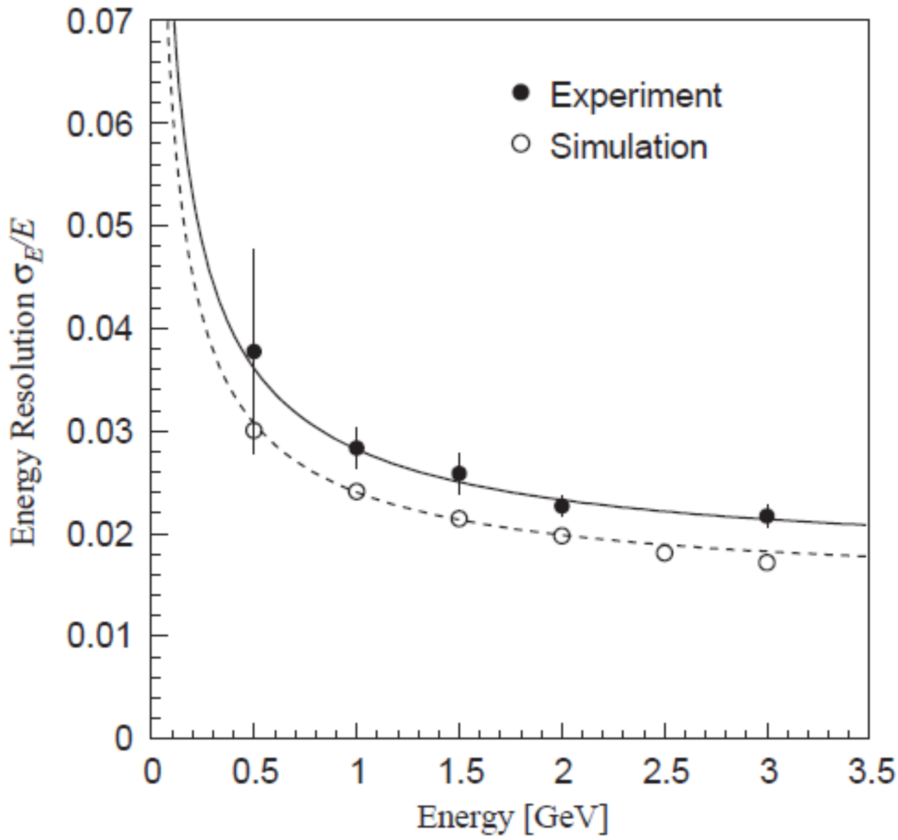

Figure 2: Energy resolution performance of the BSO crystal calorimeter in a 0.5 – 3 GeV electron beam test.

PWO, commonly used for crystal detectors in high energy experiments, such as the CMS barrel and end-cap calorimeter at LHC, works in a high luminosity environment. The technique for PWO production is mature and new tests for doped PWO to improve its light output are carrying on. Figure 3 shows the excellent energy resolution performance for a PWO crystal at high energy. At low energy due to the dramatic increasing noise rate, the energy resolution is around 6% at 3 GeV. Although its light output is not as good as BSO, it could potentially be a candidate for our demands. Thus the performance of the doped PWO needs to be evaluated for intermediate to low energy region that we are interested in (2-5 GeV). That is also one of the goals of this R&D.

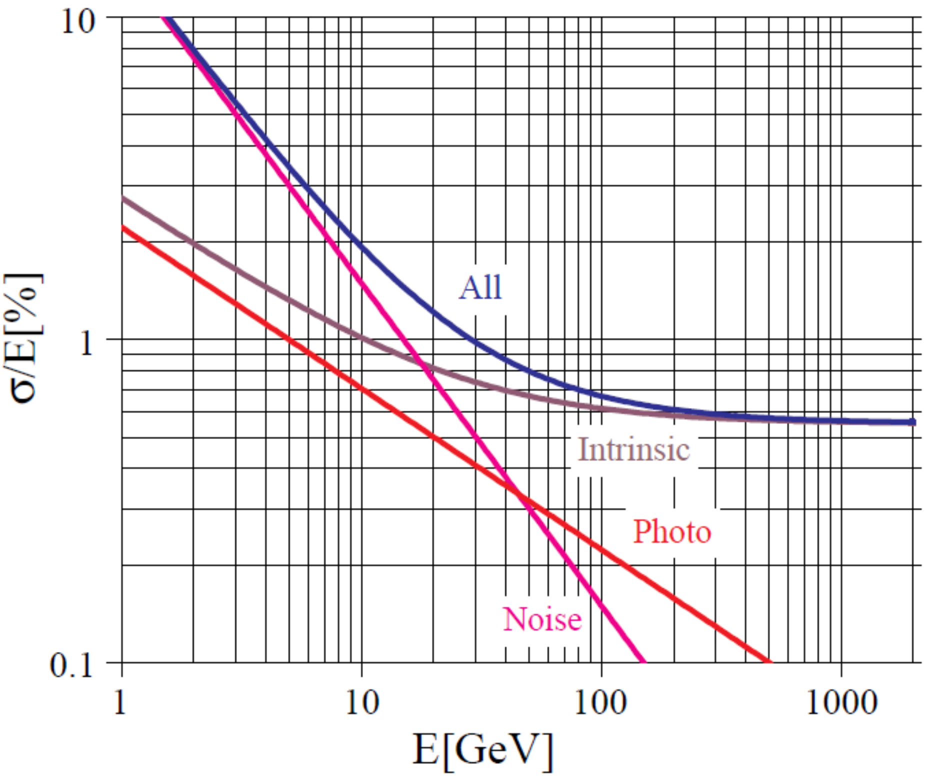

Figure 3: Sources of the energy resolution of a PWO crystal calorimeter.

The resistance to irradiated damage of the PWO crystal is acceptable. Figure 4 indicates the light-yield loss of the PWO crystal under different dose from CMS. At eta = 2.3, dose = 3.9 Gy/h, the light-yield loss is in a level of 10% for the barrel calorimeter and 15% for the end-cap.

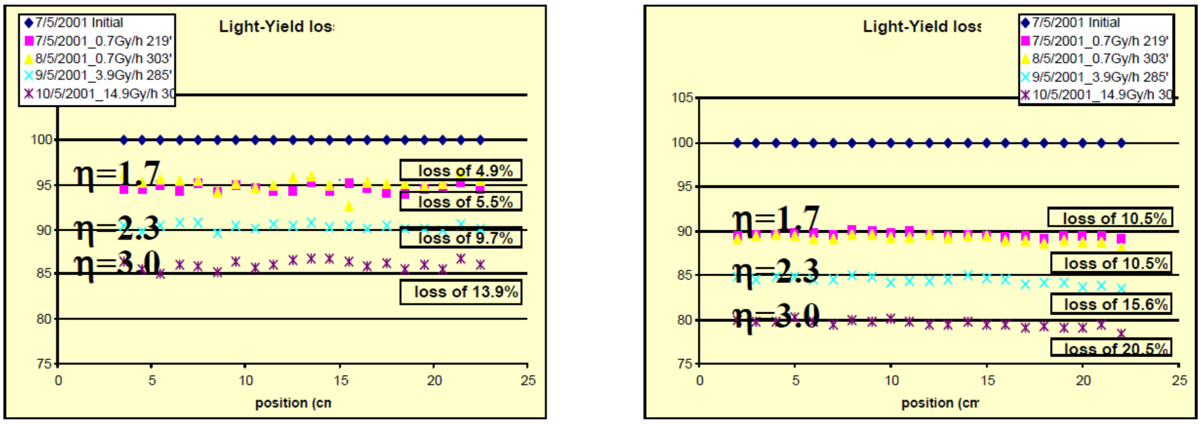

Figure 4: Irradiation test of the PWO crystals in different eta under different dose by CMS. Left panel: the barrel calorimeter. Right panel: the end-cap calorimeter.

A crystal detector, because of superior performance for electron/photon measurements, may be used in the very forward direction of electron beam for an EIC detector system or eSTAR upgrade option. Figure 5 provides an eSTAR concept of the forward calorimeter in the electron side.

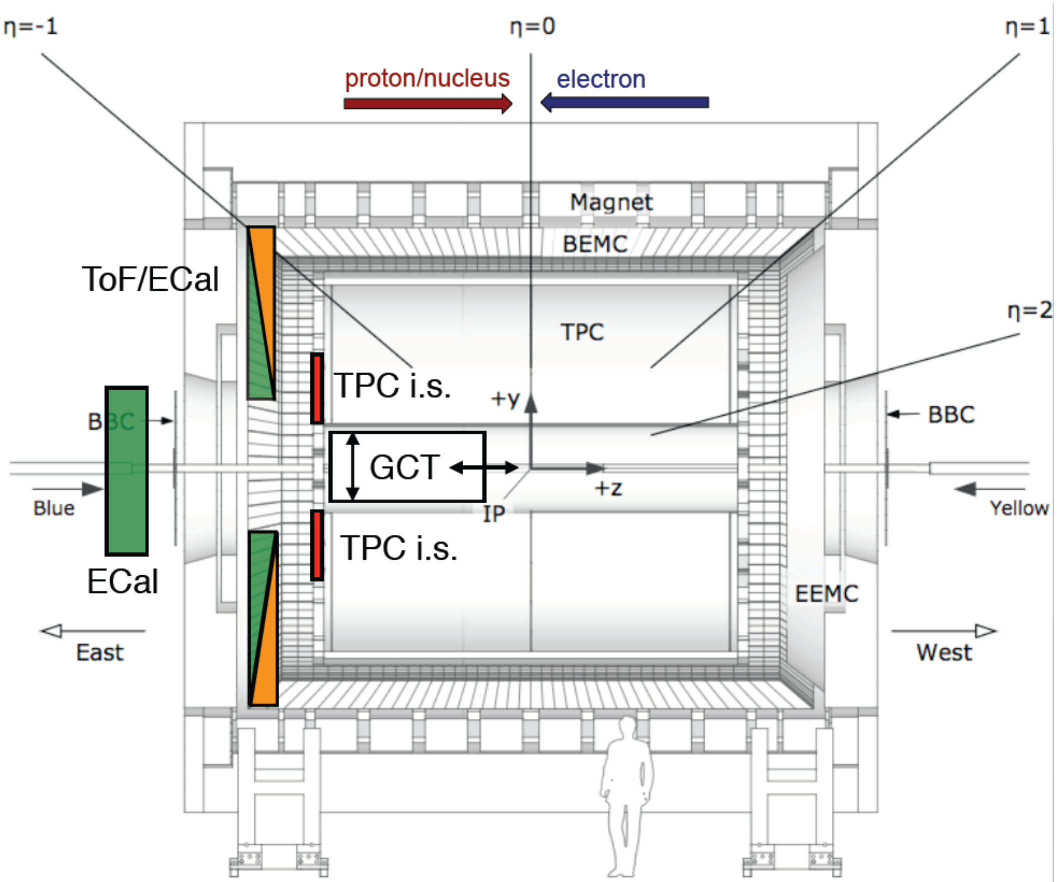

Figure 5: An eSTAR concept of the forward calorimeter ($\eta < -2$) in the electron side.

2) Chinese Crystal Manufacture Information

Viable Chinese crystal vendor: Shanghai SICCAS High Technology Corporation, a research-based enterprise wholly invested by Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS), is able to supply crystals with high quality for worldwide customers, especially suitable for crystal detectors in high energy experiments, such as Jefferson Lab (USA), KEK (Japan), INFN (Italy), PANDA (Germany), etc. SICCAS has achieved several PWO research achievements possessing independent intellectual property rights, eg. the second prize of the National Technology Invention Award (2007), the CMS Crystal Award (2008).

The BSO R&D is a new project of SICCAS, they developed technology to produce high quality BSO crystals. Now a small sized BSO crystal sample is delivered to University of Science and Technology of China (USTC) for test. USTC has an experienced research group collaborated with SICCAS for new scintilator crystal R&D, crystal property test, etc. USTC participated in the CMS/ECAL project. We have developed in technique and knowledge of crystal R&D, such as PWO. So far we already did a preliminary testing for the new coming doped PWO sample from SICCAS, the light out-put has been improved by a factor of 2.

3) Plan and Goals of the Proposed R&D project

- We work closely with SICCAS and we have a reliable crystal vendor that can produce crystals meeting our specifications at a manageable cost (the price of the crystals recently provided by the SICCAS are list in Table I).
- We now ordered small samples of PWO and BSO crystals from SICCAS for performance test then send feed-back to SICCAS to improve the production technics. Comparison between PWO and BSO will be made, such as cost, properties, etc.
- Simulations are planned to be done for the detector design and for studying the performance of the crystal detectors according to the energy resolution requirement.
- We need to purchase 5x5 crystals array each with suitable size and length (e.g. 22mmx22mmx180mm) for prototype. That will be a significant cost of the project.
- The readout scheme will also require careful thinking. For the first step we will use PMT read-out. We may be interested in the ALICE PHOS –like readout, which can be phase 2 part of the R&D.
- We may plan a beam testing either at CERN or at FNAL or at SLAC.
- Further we would use APD for read-out, the electronics such as preamp is also needed.

4) Testing

The crystal light output testing system is designed as shown in Figure 6. The PWO crystal is put in a radiative source. The light produced in the crystal is collected by the PMT (R5611). The electrical signal is amplified by a factor of 10^7 after converted from the photon, which will result in a pulse as output. Its electrical charge Q is proportional to the number of light electrons. The analog signal will be converted to be analyzable from an analog-to-digital convertor (ADC), see Figure 7. We used two types of the ADC: NIM-QVT3001 or CAMAC-ADC2249W. By changing the width of the gate, we can measure different quantity of the charge in different integrated time. The PWO crystal light output is temperature dependent as shown in Figure 8, at low temperature the light output is high but decreasing fast. Our testing is able to determine the working temperature that a high light output but with a good temperature stabilization is required.

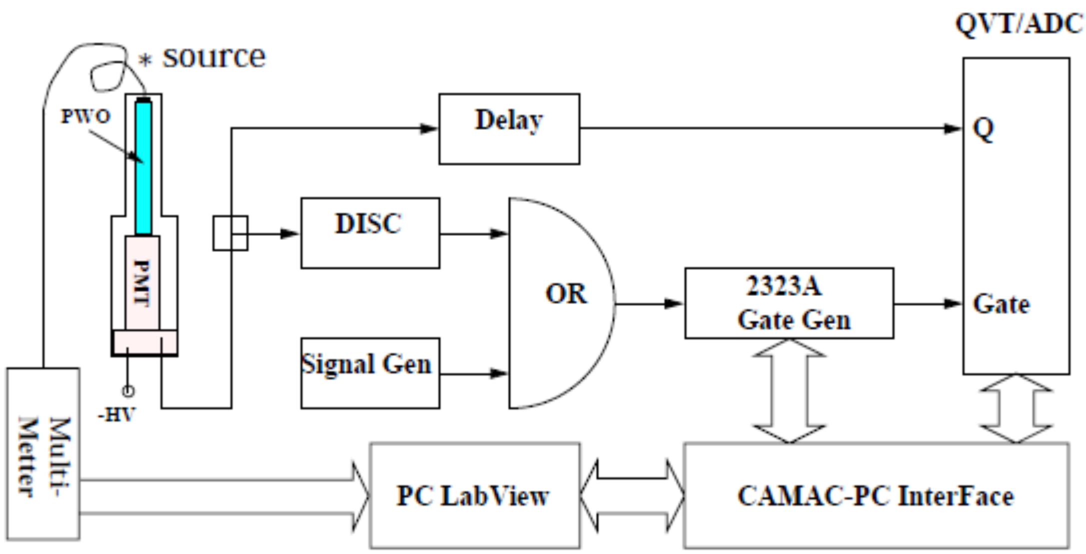

Figure 6: PWO light output testing system.

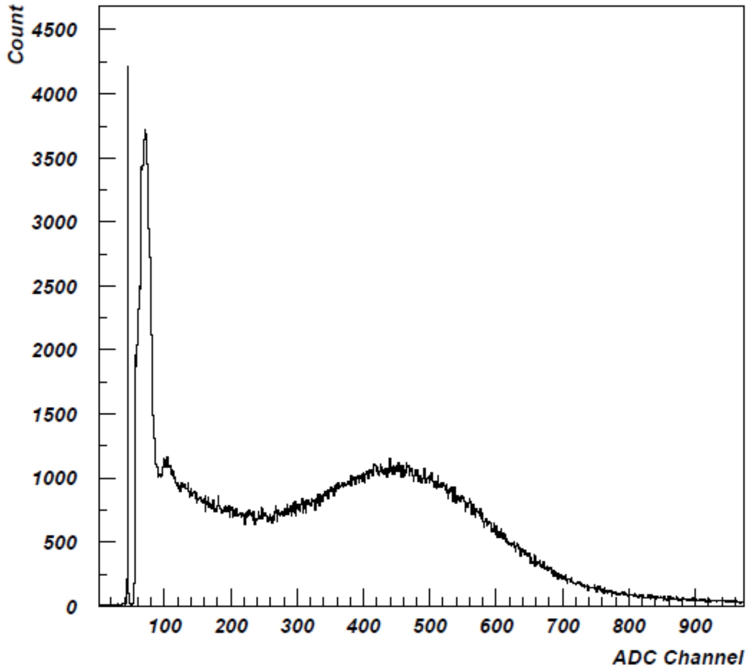

Figure 7: ADC signal of a PWO crystal from the test system.

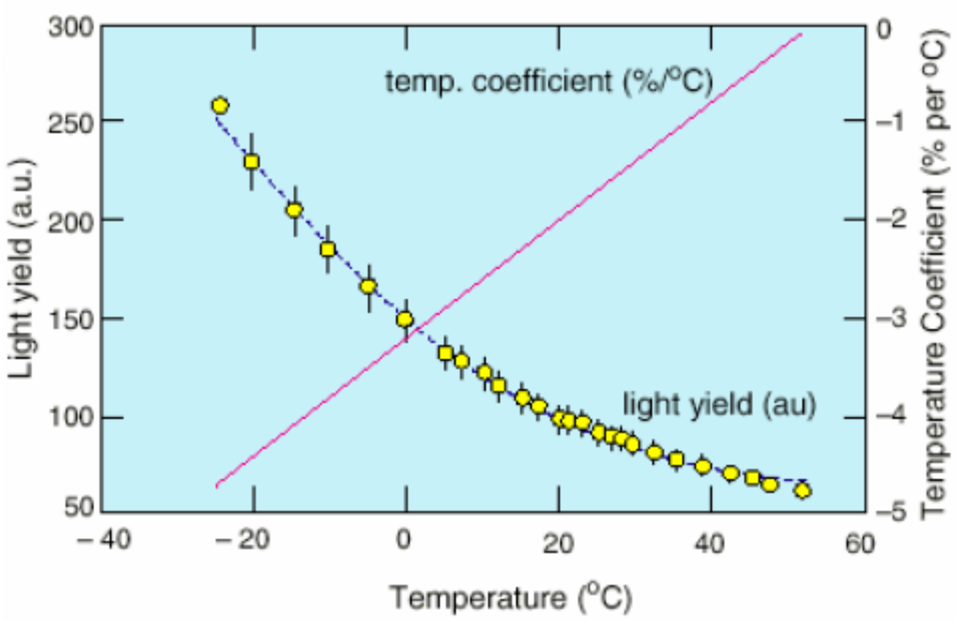

Figure 8: Temperature dependence of PWO crystals.

5) Read-out

We have experienced group for electronics and read-out design. We may use the similar read-out system as CMS calorimeter, see Figure 9.

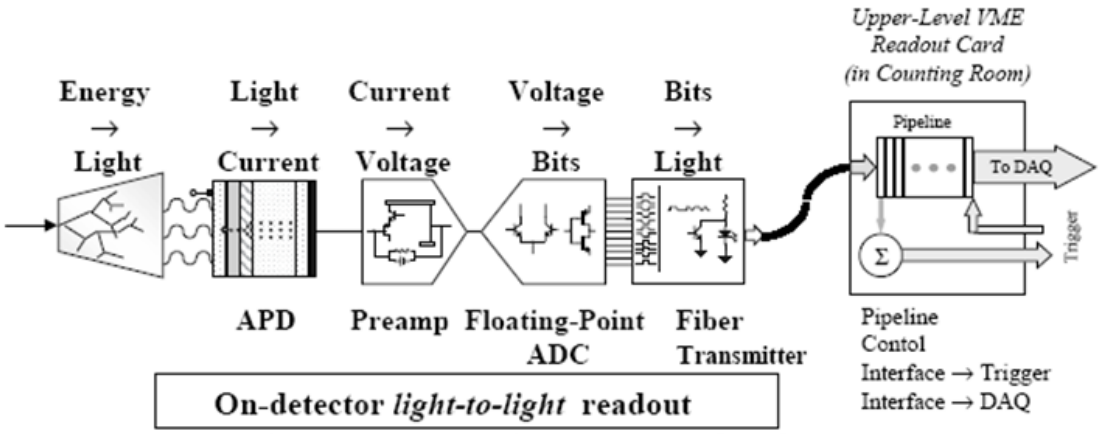

Figure 9: CMS read-out system.

6) Budget

The price of PWO crystal used in CMS is ~7 USD/cc. Now the price increases to >10 USD/cc, depending on the quantities needed. And the price of new doped PWO may be even higher. The price of BSO crystal is slightly higher than PWO, ~ 15-20 USD/cc.

We use PMT R5611, the price is 1.5k – 2k USD per PMT.

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